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ABSTRACT

The engineering profession and, consequently, the education process for engineers must respond to several new realities in order to be successful in the 21st century. Some aspects of the new reality that are relevant to engineering education are as follows: the globalization of commerce; the information revolution; innovations in technology; the new emphasis on sustainable development; recognition of the need for lifelong learning and gender equality; the role of engineers in nations' future prosperity and the political process; the rise of multinational corporations and new start-up companies; the trend toward transformation of the study of engineering into the "new liberal arts" coupled with emphasis on basic engineering/specialization; industry-university partnerships; the need for engineers to receive training in innovation/entrepreneurship and communication; and the need to attract more women into the field of engineering. In recognition of the new reality, the University of Calgary in Alberta has adopted the position that a four-year university program in engineering is reasonable for producing graduates that either enter the work force as "engineers-in-training" or enter further studies in engineering or in business, law, or medicine. However, the university strongly recommends an additional 16-month internship in industry for students wishing to advance into leadership roles. (MN)

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Crossroads of the New Millennium

Engineering Education For Leadership In The 21st Century

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Workshop 2

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Abstract

The 21st Century will be one of intense globalisation of commerce, further strengthening of the "information society", major innovations in technology, sustainable development, gender equality and life long learning. Innovation through engineering and global commercialisation of such innovations will be the key to the prosperity of nations.

Engineering today is the design of safe, practical and economical solutions to complex technological problems. In Canada and many other countries, it is a "regulated" profession that operates through a code of ethics. The high level of our civilization is very much due to engineering advances. The next century must see engineers play a leadership role not only as problem solvers and innovators, but also in international commerce, public policy and public leadership.

Engineering as a subject area is the "new liberal arts". Today, a basic degree in engineering easily qualifies one to pursue further studies in commerce, medicine, law and many other fields. The converse in not true.

Engineering education in the next century will provide much more than scientific, mathematical, technical, information technology and design knowledge and skills. The men and women who will be 21st Century engineers will exhibit leadership and multi-disciplinary teamwork, and have a clear understanding of the history of science and of sustainable development. They will be multilingual and excellent communicators. They will have a background in commercialisation and start-up of enterprises. They will be trained to be life long learners. They must be ethical and highly disciplined individuals who will be an example to other sectors of society.

The rapidly developing engineering curriculum at the University of Calgary is designed to produce the 21st Century engineer.

The 21st Century will see engineers assume a more prominent role, not only as innovators and technological guardians of the knowledge-based society, but also in international commerce and leadership of successful nations.

Engineering Education for Leadership in the 21st Century

THE 21ST CENTURY

The engineering profession and, consequently, the education process for engineers, must respond to several new realities in order to be successful in the 21st Century. Programmes of engineering education that respond to the new reality will expand and be successful while others will necessarily shrink. Some aspects of the new reality that are relevant to engineering education are briefly discussed in this section.

GLOBALISATION OF COMMERCE

The globalisation of commerce essentially means more opportunities globally for economic activity, including engineering services, as well as more competition. This is caused by the "free trade" movement, ability to communicate more or less instantaneously and emergence of English as the world language for business and science.

INFORMATION REVOLUTION

We are privileged to be at the inception of the information revolution. We have the ability to store large knowledge and databases and to access them worldwide through the internet and the web. Further, advanced high speed computing capability is available at one's fingertips. The information highway leads not only to abstract information but also to people at dispersed locations. High-speed real time video conferencing and web based communication makes one's location in the world essentially irrelevant with respect to conducting business, engineering or educational activities.

INNOVATIONS IN TECHNOLOGY

The rapid progress made by humankind in the last few centuries, and indeed millennia, is due in significant part to innovation through engineering. From the pyramids of Egypt, to the massive irrigation systems of Sri Lanka, to the highways and aqueducts of the Romans, to the industrial revolution originating in Europe and the current North American lead information revolution, it is innovation through engineering that has led the way. The 21st Century will clearly see an acceleration of the process with information and telecommunications technology, nanotechnology, environmentally friendly advanced manufacturing, bioengineering, software engineering and space engineering being some of the technologies at the forefront.

We must also deal with "technologiefeindlichkleit" which means essentially..."mistrust of technology". This is faced not only by engineering but by other technologies such as pharmaceuticals and genetics. The engineering industry as well as educators must explicitly take society's mistrust of technology into account in our planing. This mistrust is caused in part by past errors by the profession and industry. It can only be ameliorated by a sustained long term effort to keep in mind the overall social good and the need for sustainable development when undertaking engineering projects.

SUSTAINABLE DEVELOPMENT

The understanding that we must ... "meet the needs and aspirations of our generation without jeopardizing the needs and aspirations of future human generations and the well being of other species", i.e. practice sustainable development, is, taking hold. Consequently, engineering must be redefined as the harnessing of nature and knowledge for the benefit of all species and generations. Engineering for the environment is therefore, not only cleaning up the mistakes of the past, but also ensuring that, in future, manufacturing will be based on clean technologies and life cycle management.

LIFELONG LEARNING

Given the rapid rate at which technology is advancing and new information is becoming available, it is clear that one does not "stop learning" when one obtains a parchment and joins the workforce. Continuous upgrading of one's skills, abilities and knowledge is essential to being successful as an individual or as a company. Not only the recipients of learning, but the providers of learning, must adjust to this need for continuous education. It is obvious that a major mode for continuous learning will be the WWW. However, the inherent desire to learn directly from a knowledgeable human being will not disappear.

GENDER EQUALITY

Gender Equality is another new reality of the modern age. The engineering profession has been slower to recognise this fact in comparison to other professions such as medicine and law. The obvious fact, that the talents and the genius of half the population has not been available to the profession in the past, must be recognised and remedied rapidly for the good of society as a whole. Canada is a world leader in striving for true gender balance in engineering and engineering education.

PROSPERITY OF NATIONS – FUTURE ROLE OF ENGINEERS

The prosperity of nations will depend in the long run on their ability to succeed in the new knowledge based world economy. Innovation through engineering, the ability to create knowledge based products and services, and the ability to trade such products worldwide will be key. Highly educated human resources that generate the knowledge required, that also have a high degree of innovation and entrepreneurship, will be required.

The ability to create knowledge, to be innovative and entrepreneurial is an intrinsic human characteristic. However, one must have the right political, economic and cultural climate that enables these latent characteristics to flourish. Democracy, a free judiciary, a free market, equal treatment of all people, an efficient education system and honesty are some of the key conditions.

POLITICAL LEADERSHIP

The political leadership in many countries is weak and rampant with corruption and nepotism. They are unable to set up public policies that help to produce prosperity for all their peoples in the 21st Century. One of the keys to unlocking this problem is for engineers and other professionals, who follow clear codes of ethics [APEGGA (2000)], to be more active in setting and enacting public policies. This means assuming roles of political leadership as opposed to being simply technocrats.

MULTI-NATIONALS

Multi-national and large corporations are another artifact of the global economy. They too must be flexible, innovative and remain entrepreneurial and have a long-term vision to succeed. They are also highly influential. Enlightened leadership that looks beyond the short term "bottom line" is critical for such corporations. Engineers must aspire to such leadership roles in large corporations.

NEW START-UPS

Equally important, if not more so, in the new century, are "start up" companies that are knowledge based. Since innovation through engineering is key to such start-ups, engineers must have the entrepreneurial ability to meaningfully take their innovations to the market place.

ENGINEERING – THE NEW LIBERAL ARTS

The study of engineering is well on its way to becoming the "new liberal-arts" of the 21st Century. In particular, in Canada, the engineering curriculum includes the study of mathematics, basic sciences, engineering science and engineering design. Further, the study of the relationship between engineering and society, safety, ethics, communications and complementary studies (typically traditional liberal arts courses) is mandatory [CEAB (1999)]. Such a broad-based curriculum is what a 'liberal-arts' programme is supposed to be. Indeed, according to Winchester (1996) the original liberal arts of a few centuries ago had certain similarities to today's engineering curriculum.

Today, many that graduate with a bachelor's degree in engineering pursue further studies in business, law, and medicine and other fields. In fact, it is well accepted that they excel in such programmes. However, very few play major roles in the development of public policy or take on leadership positions, either of large corporations or nations.

The "New Engineering" curricula for the 21st Century must improve upon the successful curricula of the last few decades.

BASIC ENGINEERING/SPECIALISATION

The "New Engineering" must respond to the new reality. The major responsibility in this regard lies with educational institutions. Strong basic engineering skills must be given to all engineers to ensure their adaptability in a rapidly changing world. At the same time, the explosive growth of knowledge and requirements of industry point towards increasing specialisation. Some examples are: Software Engineering, Intelligent Manufacturing, Bio Engineering, Generalised Positioning Systems (GPS) and Urban Systems Engineering. Engineering education must respond to the competing need for basic engineering skills and for specialisation.

INDUSTRY/UNIVERSITY PARTNERSHIP

Efficiency requires that industry and universities form partnerships to provide life long engineering education. This does not mean that universities will simply provide only for industrial needs. Students must be imbued with the greater responsibility to society as a whole and to sustainable development, during the educational process. Industry in turn must pick up some of the support withdrawn by governments by providing in-kind services such as teaching portions of courses and by supporting "experiential learning" through internship

programmes. Further, the need to be competitive implies that large-scale engineering and research projects require not only multidisciplinary teams but also university and industry working together.

INNOVATION/ENTREPRENEURSHIP

The ability to innovate through engineering is an essential aspect of being competitive in the global village. For example, this realisation has caused an "innovation offensive" in Germany. New Engineering education consequently is not simply technical education but the training of engineers to innovate and to be entrepreneurial. It has even been suggested that the term "engineer" be changed to "technovator".

COMMUNICATIONS

As engineering problems become more complex, the technical tools for their solution also become increasingly sophisticated. It is demonstrated regularly that engineers are up to the challenge of developing the technical solutions. However, defining some of the major engineering problems on a larger scale requires significant public consultation, i.e. two-way communications. Communicating complex solutions and in some cases obtaining public "buy-in" is equally important. The engineering culture of working with computers and using a highly analytical approach does not facilitate clear communication with others. Even within corporations, engineers must communicate more to support and advance their ideas and proposals. To emerge from the "back-rooms", engineers must be brought-up in a culture of teamwork, collaboration and constant clear communication. The new engineering curricula must reflect that imperative.

COMPLEMENTARY STUDIES

An understanding of history, the political process, psychology and social anthropology for example is important in formulating public policy and assuming leadership roles. Room must be found in the 21st Century Engineering curriculum for such studies.

BIOLOGY

Sustainable development is obviously related to humans and other species, both plant and animal. The development of "sustainable" solutions to major engineering problems, indeed the comprehension of what the problems are in the broader context, requires an understanding of biological system. It is a worldwide phenomenon that, in the last century, students planning to study engineering were discouraged from studying biology at the secondary school level. That lack of knowledge has lead to the development of environmentally

"unfriendly" and non-sustainable engineering projects and a resulting increase in "technologiefenidlichkleit". We must work with the secondary school systems and our own curricula to provide a better understanding of biological systems to those entering the engineering profession.

WOMEN IN ENGINEERING

Given that slightly more than half the population consists of women, the engineering profession would stand to lose unless it attracts significant numbers of women. Society as a whole would lose if the brainpower of that population were lost to a key profession on which we depend for our safety and for technological innovations. The University of Calgary has been a leader in promoting gender equality in engineering. It was the first to establish a women in engineering standing committee with a mandate to improve the quality of the experience of women in engineering education, to encourage further education, e.g. from Masters to PhD level, and to attract increasing numbers. We have also been pro-active in attracting and recruiting women faculty and now have the largest cohort in Canada of 12 faculty members. The function of faculty members to be "role models" for women students cannot be underestimated. We have also established the NSERC/PetroCanada Prairie Region Chair in Women in Engineering and Science to investigate all aspects of the role of women in science and engineering.

THE UNIVERSITY OF CALGARY APPROACH (www.eng.ucalgary.ca)

One must balance the competing requirements that are to be accommodated within a curriculum with the cost, to students and society, of the educational process. The University of Calgary position is that, given the level of high school education in Canada, a four year university programme in engineering is reasonable for producing graduates that either enter the workforce as "engineers-in-training" or go on to higher studies in engineering (Masters, Ph.D.), or further studies in business (MBA), law or medicine. However, an additional 16 month internship in industry (May xx to August xx + 1) amounting to a 5 year programme, is highly encouraged for those who wish to become "superior graduates" with the opportunity to obtain the plum employment opportunities and advance rapidly into leadership roles.

A PROGRAMME FOR THE 21ST CENTURY

Nine degree programmes are offered, a balance of the four traditional "pillars" of engineering: Chemical, Civil, Electrical and Mechanical Engineering, with five more programmes appropriate for the modern economy: geomatics, manufacturing, oil and gas, computer and software engineering. Several "minor" specialisations (options) are offered

within certain programmes thus maintaining the tension between basic and specialized knowledge: environmental, transportation, structures (civil engineering), petroleum (chemical and mechanical engineering), computer integrated manufacturing (mechanical engineering).

A degree in General Engineering with special emphasis on engineering science and team based engineering design, as well as significant liberal arts, history of science, communication and second languages content, is being planned. It will also have a mandatory research thesis as well as a specialisation in fourth year on an advanced topic, e.g. nanotechnology. Tentatively titled the "Galileo Programme" the degree will be open, through an entrance examination, to a small cohort (say 50) of the best students worldwide.

Minor specialisations in bioengineering (in civil, chemical, electrical, mechanical, geomatics) and mechatronics (mechanical) are at the advanced planning stage. We see bioengineering as a growth specialisation area within many of the main branches of engineering at the undergraduate level, and as a freestanding programme at the postgraduate level.

ENGINEERING INTERNSHIP

Engineering Internship is a flagship programme of experiential learning of 16 months duration that is "sandwiched" between the third and fourth year regular academic programmes. Industry gains access to students with three years of engineering studies who can be expected to undertake a challenging work experience. The duration of the placement allows corporations to have a reasonable expectation of accomplishing a completed project. The interns thrive in the situation where they are challenged, and also spend sufficient time at a corporation to understand corporate culture, communications as well as take advantage of networking opportunities. The key to the success of the internship concept is the ability to provide a meaningful advanced and sustained work experience over 16 months. Additionally, students obtain exposure to other companies by doing four-month "summer" jobs after the first and second regular academic years respectively. With only one work placement per student, internship is also very cost effective to operate. We expect participation in internship to stabilize at about 75% with the remaining 25% being students planning for further studies in engineering, business, law or medicine. We expect students graduating with internship to play significant leadership roles in industry in future.

DOUBLE DEGREE PROGRAMMES

Five year double degree programmes are available with the humanities, social sciences and fine arts, leading to an extremely broad and well-rounded education. The graduates from the

humanities and social sciences double degrees are ideally suited and well positioned to play roles in developing public policy and even assume political leadership roles in the future. The study of a second language, through a double degree in the humanities, will facilitate international business opportunities.

ENTREPRENEURSHIP and ENTERPRISE DEVELOPMENT

In support of the philosophy of encouraging engineers to innovate and then incorporate "start-up s", a minor specialisation in entrepreneurship and enterprise development is available to engineering students, in co-operation with the Faculty of Management. The programme requires six additional months of study, which can be accomplished by taking spring/summer courses, or by stretching the four-year degree by another academic term. The minor is also intended to help students who join smaller firms in playing more than a technical role.

SPECIAL ADMISSION REQUIREMENTS

Typically, students planning to take engineering do not pursue studies in biology in secondary school. Such studies are important in understanding sustainable development and for further studies in, for example, environmental and bioengineering. The University of Calgary has an admission policy that allows us to admit students who have opted for biology over calculus, with the promise that they follow a special programme in first year, that includes catch up courses in calculus.

CONCLUSION

The 21st Century engineering curriculum is designed to provide the right education for students planning a variety of career paths. It allows a reasonable degree of specialisation within a basic degree. It positions students for further studies in engineering, law, medicine, and business. Degree programmes ranging from traditional to post-modern (e.g. software engineering) is available. Internship programmes allow for a significant industry experience, both technical and otherwise, that enables us to produce "superior graduates" suitable for leadership positions.

The 5 year double degree programmes provide a broader education befitting those aiming for a career that includes leadership not only of corporations but roles in formulating and providing leadership in public policy. An extra degree minor provides a learning experience in entrepreneurship and enterprise development for those planning to start up a business or join a small corporation.

With such a curriculum, engineering can emerge as the "new liberal arts" programme that produces engineering, corporate and national leaders for the 21st Century.

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The many innovative academic programmes of the Faculty of Engineering were planned and designed by enlightened academic staff members. This paper builds further on a previous paper titled "Challenges and Opportunities in Engineering Education".

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